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### (54) Production of multimodal polyethelene

(57) A process for the preparation of polyethylene resins having a multimodal molecular weight distribution which comprises:

(i) contacting ethylene monomer and a comonomer comprising an alpha-olefin having from 3 to 10 carbon atoms with a first catalyst system in a first reactor under first polymerisation conditions to produce a product comprising a first polyethylene having a first molecular weight and a first density and the first catalyst system comprising (a) a metallocene catalyst selected from one of components A or B, component A comprising a bis tetrahydroindenyl compound of the general formula  $(\text{IndH}_4)_2\text{R}''\text{MQ}_2$  in which each Ind is the same or different and is indenyl or substituted indenyl,  $\text{R}''$  is a bridge which comprises a  $\text{C}_1$ - $\text{C}_{20}$  alkylene radical, a dialkyl germanium or silicon or siloxane, or an alkyl phosphine or amine radical, which bridge is substituted or unsubstituted, M is a Group IVB transition metal or vanadium and each Q is hydrocarbyl having 1 to 20 carbon atoms or halogen and component B comprising a metallocene catalyst of general formula  $\text{R}''(\text{CpR}_m)(\text{Cp}'\text{R}'_n)\text{MQ}_2$ , wherein Cp is a cyclopentadienyl moiety,  $\text{Cp}'$  is a substituted or unsubstituted fluorenyl ring; each R is independently hydrogen or hydrocarbyl having 1 to 20 carbon atoms in which  $0 \leq m \leq 4$ ; each  $\text{R}'$  is independently hydrocarbyl having 1 to 20 carbon atoms in which  $0 \leq n \leq 8$ ;  $\text{R}''$ , M and Q are each as defined above, the metallocene component B having a centroid-M-centroid angle in the range  $105^\circ$  to  $125^\circ$ ; and (b) a cocatalyst which activates the catalyst component;

(ii) providing a second polyethylene having a second lower molecular weight and higher density than the first molecular weight; and

(iii) mixing together the first and second polyethylenes to form a polyethylene resin having a multimodal molecular weight distribution.

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## Description

[0001] The present invention relates to a process for the preparation of polyethylenes, having a multimodal molecular weight distribution, more particularly a bimodal or trimodal molecular weight distribution and exhibiting outstanding mechanical properties for blow-molding, film and pipe applications.

[0002] Polyolefins such as polyethylenes which have high molecular weight generally have improved mechanical properties over their lower molecular weight counterparts. However, high molecular weight polyolefins can be difficult to process and can be costly to produce. Polyolefins having a bimodal molecular weight distribution are desirable because they can combine the advantageous mechanical properties of high molecular weight fraction with the improved processing properties of the low molecular weight fraction.

[0003] For many HDPE applications, polyethylene with enhanced toughness, strength and environmental stress cracking resistance (ESCR) is important. These enhanced properties are more readily attainable with high molecular weight polyethylene. However, as the molecular weight of the polymer increases, the processability of the resin decreases. By providing a polymer with a broad or bimodal MWD, the desired properties that are characteristic of high molecular weight resin are retained while processability, particularly extrudibility, is improved.

[0004] There are several methods for the production of bimodal or broad molecular weight distribution resins: melt blending, reactor in series configuration, or single reactor with dual site catalysts. Use of a dual site catalyst for the production of a bimodal resin in a single reactor is also known.

[0005] Chromium catalysts for use in polyolefin production tend to broaden the molecular weight distribution and can in some cases produce bimodal molecular weight distribution but usually the low molecular part of these resins contains a substantial amount of the comonomer. Whilst a broadened molecular weight distribution provides acceptable processing properties, a bimodal molecular weight distribution can provide excellent properties. In some cases it is even possible to regulate the amount of high and low molecular weight fraction and thereby regulate the mechanical properties.

[0006] Ziegler Natta catalysts are known to be capable of producing bimodal polyethylene using two reactors in series. Typically, in a first reactor, a low molecular weight homopolymer is formed by reaction between hydrogen and ethylene in the presence of the Ziegler Natta catalyst. It is essential that excess hydrogen be used in this process and, as a result, it is necessary to remove all the hydrogen from the first reactor before the products are passed to the second reactor. In the second reactor, a copolymer of ethylene and hexene is made so as to produce a high molecular weight polyethylene.

[0007] Metallocene catalysts are also known in the production of polyolefins. For example, EP-A-0619325 describes a process for preparing polyolefins such as polyethylenes having a multimodal or at least bimodal molecular weight distribution. In this process, a catalyst system which includes at least two metallocenes is employed. The metallocenes used are, for example, a bis(cyclopentadienyl) zirconium dichloride and an ethylene-bis(indenyl) zirconium dichloride. By using the two different metallocene catalysts in the same reactor, a molecular weight distribution is obtained which is at least bimodal.

[0008] Polyethylene resins are known for the production of pipes. Pipe resins require high resistance against slow crack growth as well as resistance to rapid crack propagation yielding impact toughness. There is a need to improve in the performance of currently available pipe resins.

[0009] The present invention aims to overcome the disadvantages of the prior art.

[0010] The present invention provides a process for the preparation of polyethylene resins having a multimodal molecular weight distribution which comprises:

- (i) contacting ethylene monomer and a comonomer comprising an alpha-olefin having from 3 to 10 carbon atoms with a first catalyst system in a first reactor under first polymerisation conditions to produce a product comprising a first polyethylene having a first molecular weight and a first density and the first catalyst system comprising (a) a metallocene catalyst selected from one of components A or B, component A comprising a bis tetrahydroindenyl compound of the general formula  $(\text{IndH}_4)_2\text{R}''\text{MQ}_2$  in which each Ind is the same or different and is indenyl or substituted indenyl,  $\text{R}''$  is a bridge which comprises a  $\text{C}_1$ - $\text{C}_{20}$  alkylene radical, a dialkyl germanium or silicon or siloxane, or an alkyl phosphine or amine radical, which bridge is substituted or unsubstituted, M is a Group IVB transition metal or vanadium and each Q is hydrocarbyl having 1 to 20 carbon atoms or halogen and component B comprising a metallocene catalyst of general formula  $\text{R}''(\text{CpR}_m)(\text{Cp}'\text{R}'_n)\text{MQ}_2$ , wherein Cp is a cyclopentadienyl moiety,  $\text{Cp}'$  is a substituted or unsubstituted fluorenyl ring; each R is independently hydrogen or hydrocarbyl having 1 to 20 carbon atoms in which  $0 \leq m \leq 4$ ; each  $\text{R}'$  is independently hydrocarbyl having 1 to 20 carbon atoms in which  $0 \leq n \leq 8$ ;  $\text{R}''$ , M and Q are each as defined above, the metallocene component B having a centroid-M-centroid angle in the range  $105^\circ$  to  $125^\circ$ ; and (b) a cocatalyst which activates the catalyst component;
- (ii) providing a second polyethylene having a second lower molecular weight and higher density than the first molecular weight; and

(iii) mixing together the first and second polyethylenes to form a polyethylene resin having a multimodal molecular weight distribution.

[0011] Optionally, when the metallocene catalyst is component A, the polyethylene resin is a pipe resin having an HLMI of from 3 to 10 g/10min and a density of from 0.95 to 0.96 g/ml.

[0012] The first polyethylene may be monomodal or bimodal, the second polyethylene may have a monomodal molecular weight distribution and may have been produced using a metallocene catalyst, a Ziegler-Natta catalyst or a chromium-oxide based catalyst. Alternatively, the second polyethylene may have a bimodal molecular weight distribution and has been produced using one or two of those different catalyst systems. The first and second polyethylenes may be mixed together with a third polyethylene to provide a trimodal molecular weight distribution in the resultant polyethylene resin. The third polyethylene may be produced using a metallocene catalyst, a Ziegler-Natta catalyst or a chromium-oxide based catalyst.

[0013] The first and second polyethylenes may be mixed by chemical blending or physical blending. For chemical blending, the first and second polyethylenes are made in two serially connected reactors using a common metallocene catalyst component A or B, or three serially connected reactors for making a polyethylene resin having a trimodal molecular weight distribution, in which a third polyethylene is chemically blended with the first and second polyethylenes. In an alternative arrangement, the first and second polyethylenes may be chemically blended as foreshad, and then physically blended with a third polyethylene to produce a trimodal molecular weight distribution. In further alternative arrangements, the polyethylene resin has a bimodal molecular weight distribution and is produced by physically blending the first and second polyethylenes together or alternatively the polyethylene resin has a trimodal molecular weight distribution and is produced by physically blending together the first, second and third polyethylenes. Alternatively, a trimodal PE may be produced in three reactors in series.

[0014] In one particular embodiment, a polyethylene pipe resin produced in accordance with the present invention has a high molecular weight, low density fraction produced by a metallocene catalyst of component B, a medium density fraction produced by a chromium-based catalyst and a high density fraction produced by a metallocene catalyst of component A, these three fractions being physically blended together to form the resultant polyethylene resin. The low and high density fractions together define a bimodal distribution.

[0015] In an alternative embodiment, the polyethylene pipe resin comprises a physical blend of three polyethylenes produced by three different metallocene catalysts. Thus the polyethylene pipe resin includes a low density fraction produced using the metallocene cata-

lyst of component B, a medium density fraction produced using a metallocene catalyst which could be components A and B and a high density fraction produced using a metallocene catalyst of component A.

[0016] In yet a further embodiment of the invention, the polyethylene type resin produced in accordance with the invention comprises a low density fraction produced using the metallocene catalyst of component B, a medium density fraction using a first Ziegler-Natta catalyst and a high density fraction produced using a second Ziegler-Natta catalyst, the medium and high density fractions together defining a bimodal distribution.

[0017] In a still further embodiment, a polyethylene pipe resin is produced in accordance with the invention employing a single metallocene catalyst of component A or B in two reactors in series to produce a bimodal molecular weight distribution. Typically in the first reactor of the serially connected reactors a high density low molecular weight polyethylene resin is produced which is substantially a homopolymer and in the second reactor the operating conditions are changed and the  $\alpha$ -olefinic copolymer is introduced to produce a low density high molecular weight fraction with high comonomer incorporation.

[0018] In each of these embodiments, the low density fraction produced using the metallocene catalyst of component A or B comprises at least 15 wt% of the resultant polyethylene resin. Preferably, the low density fraction produced using the metallocene catalyst component A or B has a density of not more than 0.925 g/ml, more preferably for component B not more than 0.910 g/ml, and an HLMI for component A or B of not more than 0.5 g/10min, more preferably for component B not more than 0.15 g/10 min. The HLMI is measured by the procedures of ASTM D 1238 using a load of 21.6kg at a temperature of 190°C.

[0019] The present invention is predicated on the discovery that the use of one of the metallocene catalysts components A and B enables a high molecular weight linear low density polyethylene fraction e.g. in a pipe resin to be produced, with that fraction having a very narrow molecular weight distribution. This yields both improved slow and rapid crack propagation properties as a result of a high and uniform level of comonomer distribution in the low density fraction, with a density typically lower than around 0.925 g/ml, compared to somewhat higher low density fractions achievable by Ziegler-Natta or chromium based catalysts, particularly when used in a slurry loop process. Thus the use of either of these two metallocene catalysts enables precise control of the molecular weight distribution and density of the high molecular weight fraction of a pipe resin, yielding improved mechanical properties and processability. Typically, the HLMI of the high molecular weight, low density fraction is very low, e.g. when component B is used being less than around 0.15 g/10min measured by the procedures of ASTM D 1238 using a load of 21.6 kg at a temperature of 190°C. The values of HLMI are repre-

sentative of the high molecular weight of the fraction. Typically, when component B is used overall the multimodal pipe resins of the present invention have a density of around 0.945-0.950 g/ml with an HLMI of around 3-40 g/10min. When component A is used overall the multimodal pipe resins of the present invention have a density of from 0.95 to 0.96g/ml with an HLMI of from 3 to 10 g/10min. The pipe resin consists not only of the high molecular weight fraction, but also a low molecular weight fraction whereby the pipe resin as a whole has a multimodal, for example a bimodal, molecular weight distribution. The provision of such a multimodal distribution yields a combination of improved mechanical properties of the pipe resin, without compromising the processibility.

[0020] In accordance with this invention, the low molecular weight fraction of the polyethylene resin for the production of pipes may be constituted by a second polyethylene which typically has a monomodal or bimodal molecular weight distribution and is produced by ethylene homo and/or copolymerisation in the presence of a metallocene catalyst system and/or a Ziegler-Natta catalyst system and/or a chromium-oxide based catalyst system.

[0021] A third polyethylene resin may also be provided which has a monomodal or bimodal molecular weight distribution and is produced using a metallocene catalyst system and/or a Ziegler-Natta catalyst system and/or a chromium-oxide based catalyst system but which has a different density and molecular weight distribution from that of the second polyethylene resin.

[0022] The first and second, and optionally third, polyethylenes constitute separately produced resins which may then be physically and/or chemically blended (in this case using a plurality of reactors in series) to form the composite polyethylene resin having a multimodal molecular weight distribution. The production of the polyethylene comprising the lower molecular weight fraction of the composite resin can be controlled to give the desired processing properties for the pipe resin. It has been shown that the combination of low branching (ideally no branching) in the low molecular part of the resin and high comonomer incorporation in the high molecular part significantly improves the resin properties with respect to resistance to slow crack growth and impact strength which are important properties for pipe resins.

[0023] In one preferred aspect of the invention, the first and second polyethylenes are physically blended and the first and second polyethylenes are produced using the metallocene catalysts of component B or of component A respectively. Preferably, each of the first and second polyethylenes has a density of around 0.925 g/ml. Alternatively, in a preferred embodiment the first polyethylene has a density of around 0.905 g/ml and the second polyethylene has a density of around 0.930 g/ml. More preferably, the physical blend comprises substantially equal parts by weight of the first and second polyethylenes and has an HLMI of from 7 to 7.5

g/10min. In another preferred aspect of the invention, the first and second polyethylenes are chemically blended and are produced using the metallocene catalyst of component A. Preferably, the first and second polyethylenes together have a bimodal molecular weight distribution in the LLDPE.

[0024] Embodiments of the present invention will now be described by way of example only with reference to the accompanying drawings, in which:

Figures 1 to 5 are gel permeation chromatographs of resins produced in accordance with the invention.

#### 15 METALLOCENE COMPONENTS A and B

[0025] When the metallocene catalyst is catalyst A, each bis tetrahydroindenyl compound may be substituted in the same way or differently from one another at one or more positions in the cyclopentadienyl ring, the cyclohexenyl ring and the ethylene bridge. Each substituent group may be independently chosen from those of formula XR, in which X is chosen from group IVA, oxygen and nitrogen and each R is the same or different and chosen from hydrogen or hydrocarbyl of from 1 to 20 carbon atoms and v+1 is the valence of X. X is preferably C. If the cyclopentadienyl ring is substituted, its substituent groups must not be so bulky as to affect coordination of the olefin monomer to the metal M. Substituents on the cyclopentadienyl ring preferably have R as hydrogen or CH<sub>3</sub>. More preferably, at least one and most preferably both cyclopentadienyl rings are unsubstituted.

[0026] In a particularly preferred embodiment, both indenyls are unsubstituted.

[0027] R' is preferably a methylene or ethylene bridge which is substituted or unsubstituted.

[0028] The metal M is preferably zirconium, hafnium or titanium, most preferably zirconium. Each Q is the same or different and may be a hydrocarbyl or hydrocarboxy radical having 1-20 carbon atoms or a halogen. Suitable hydrocarbyls include aryl, alkyl, alkenyl, alkylaryl or aryl alkyl. Each Q is preferably halogen. Ethylene bis (4,5,6,7-tetrahydro-1-indenyl) zirconium dichloride is a particularly preferred bis tetrahydroindenyl compound of the present invention.

[0029] The metallocene catalyst component A used in the present invention can be prepared by any known method. A preferred preparation method is described in J. Org. Chem. 288, 63-67 (1985).

[0030] When the metallocene catalyst is catalyst B, decreasing the centroid-M-centroid angle in Zr-based metallocenes of catalyst B tends to increase both the long chain branching and the comonomer incorporation of the metallocene catalyst when used for the production of polyolefins. The metallocene catalysts B of the present invention have a very open structure which permits the facile incorporation of comonomer with larger

substituents such as hexene in polyolefin production. In this way, LLDPE with densities around 0.9 or lower may be produced at a commercially acceptable polymerisation temperature in a slurry process. The production of LLDPE with such low densities has hitherto not been possible with Cr-based and closed structure Cent-Zr-Cent (>125°) metallocenes in a loop slurry process. Lower comonomer concentrations need be used in the process thereby reducing the likelihood of reactor fouling and avoiding excessive use of expensive comonomer.

[0031] Preferably Cp is a substituent cyclopentadienyl in which each R is independently XR<sup>3</sup> in which X is C or Si and each R<sup>3</sup> is independently H or hydrocarbonyl having 1 to 20 carbon atoms. More preferably the cyclopentadienyl is substituted with Ph<sub>2</sub>CH, Me<sub>3</sub>C, Me<sub>3</sub>Si, Me, Me and Me<sub>3</sub>C, Me and SiMe<sub>3</sub>, Me and Ph, or Me and CH<sub>3</sub>-CH-CH<sub>3</sub>.

[0032] Preferably, each R<sup>1</sup> is independently YR<sup>m</sup> in which Y is C or Si and each R<sup>m</sup> is independently H or hydrocarbonyl having 1 to 20 carbon atoms.

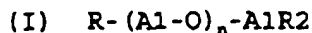
[0033] The structural bridge R<sup>2</sup> is generally an alkylene radical having 1 to 20 carbon atoms, a dialkyl germanium or silicon or siloxane, alkyl phosphine or amine, preferably Me-C-Me, Ph-C-Ph, -CH<sub>2</sub>-, Et-C-Et, Me-Si-Me, Ph-Si-Ph or Et-Si-Et.

[0034] The metal M is preferably Zr or Hf and each Q is preferably Cl.

[0035] In order to maximise comonomer incorporation, it is preferred that the centroid-M-centroid angle is no more than 119°.

[0036] The cocatalyst which activates the metallocene catalyst component can be any cocatalyst known for this purpose such as an aluminium-containing cocatalyst or a boron-containing cocatalyst. The aluminium-containing cocatalyst may comprise an alumoxane, an alkyl aluminium and/or a Lewis acid.

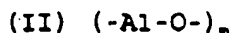
[0037] The alumoxanes used in the process of the present invention are well known and preferably comprise oligomeric linear and/or cyclic alkyl alumoxanes represented by the formula:



$$|$$

$$R$$

for oligomeric, linear alumoxanes and



$$|$$

$$R$$

for oligomeric, cyclic alumoxane, wherein n is 1-40, preferably 10-20, m is 3-40, preferably 3-20 and R is a C<sub>1</sub>-C<sub>8</sub> alkyl group and preferably methyl.

[0038] Generally, in the preparation of alumoxanes from, for example, aluminium trimethyl and water, a mixture of linear and cyclic compounds is obtained.

[0039] Suitable boron-containing cocatalysts may comprise a triphenylcarbenium boronate such as tetrakis-pentafluorophenylborato-triphenylcarbenium as described in EP-A-0427696, or those of the general formula [L<sup>+</sup>-H] + [B Ar<sub>1</sub> Ar<sub>2</sub> X<sub>3</sub> X<sub>4</sub>]- as described in EP-A-0277004 (page 6, line 30 to page 7, line 7).

[0040] The metallocene catalyst system may be employed in a solution polymerisation process, which is homogeneous, or a slurry process, which is heterogeneous. In a solution process, typical solvents include hydrocarbons with 4 to 7 carbon atoms such as heptane, toluene or cyclohexane. In a slurry process it is necessary to immobilise the catalyst system on an inert support, particularly a porous solid support such as talc, inorganic oxides and resinous support materials such as polyolefin. Preferably, the support material is an inorganic oxide in its finally divided form.

[0041] Suitable inorganic oxide materials which are desirably employed in accordance with this invention include Group 2a, 3a, 4a or 4b metal oxides such as silica, alumina and mixtures thereof. Other inorganic oxides that may be employed either alone or in combination with the silica, or alumina are magnesia, titania, zirconia, and the like. Other suitable support materials, however, can be employed, for example, finely divided functionalized polyolefins such as finely divided polyethylene. Preferably, the support is a silica having a surface area comprised between 200 and 900 m<sup>2</sup>/g and a pore volume comprised between 0.5 and 4 ml/g.

[0042] The amount of alumoxane and metallocenes usefully employed in the preparation of the solid support catalyst can vary over a wide range. Preferably the aluminium to transition metal mole ratio is in the range between 1:1 and 100:1, preferably in the range 5:1 and 50:1.

[0043] The order of addition of the metallocenes and alumoxane to the support material can vary. In accordance with a preferred embodiment of the present invention alumoxane dissolved in a suitable inert hydrocarbon solvent is added to the support material slurried in the same or other suitable hydrocarbon liquid and thereafter a mixture of the metallocene catalyst component is added to the slurry.

[0044] Preferred solvents include mineral oils and the various hydrocarbons which are liquid at reaction temperature and which do not react with the individual ingredients. Illustrative examples of the useful solvents include the alkanes such as pentane, iso-pentane, hexane, heptane, octane and nonane; cycloalkanes such as cyclopentane and cyclohexane; and aromatics such as benzene, toluene, ethylbenzene and diethylbenzene.

[0045] Preferably the support material is slurried in toluene and the metallocene and alumoxane are dissolved in toluene prior to addition to the support material.

[0046] Where the reaction is performed in a slurry using, for example, isobutane, a reaction temperature in the range 70°C to 110°C may be used. Where the reaction is performed in solution, by selection of a suitable solvent a reaction temperature in the range 150°C to 300°C may be used. The reaction may also be performed in the gas phase using a suitably supported catalyst.

[0047] In accordance with the invention, ethylene and the alpha-olefinic comonomer are supplied to the reactor containing the metallocene catalyst. Typical comonomers include hexene, butene, octene or methylpentene, preferably hexene. Hydrogen may be additionally supplied to the first reaction zone. Because the metallocene catalyst component of the present invention exhibits good comonomer response as well as good hydrogen response, substantially all of the comonomer is consumed in the first reactor in this embodiment. This produces high molecular weight polyethylene copolymer having a monomodal molecular weight distribution.

[0048] The temperature of the reactor may be in the range of from 70°C to 110°C, preferably from 70°C to 100°C.

[0049] The HLMW of the high molecular weight polyethylene fraction, comprising a linear low-density polyethylene, made in accordance with the present invention typically falls in the range 0.02 to 0.3 g/10', preferably in the range 0.03 to 0.15 g/10'. The density of the high molecular weight resin fraction is typically in the range 0.9 to 0.925 g/ml, preferably 0.905 to 0.915 g/ml. The high molecular weight polyethylene fraction preferably has a molecular weight distribution in the range 2 to 4.5, preferably around 3 and more preferably is partially long chain branched so as to facilitate processing.

#### CHROMIUM-BASED CATALYSTS

[0050] The chromium-based catalyst preferably comprises a silica, silica-alumina and/or titania supported chromium oxide catalyst. A particularly preferred chromium-based catalyst may comprise from 0.5 to 5 wt% chromium, preferably around 1 wt%, on a catalyst support. The weight percentage of chromium is based on the weight of the chromium-containing catalyst. The chromium-based catalyst may have a specific surface area of from 200 to 700 m<sup>2</sup>/g, preferably from 400 to 550 m<sup>2</sup>/g and a volume porosity of from 0.9 to 3 cc/g, preferably from 2 to 3 cc/g. The average pore radius is preferably from 100 to 1000 Å, most preferably from 150 to 250 Å.

[0051] A preferred chromium-based catalyst for use in the present invention comprises a catalyst which has an average pore radius of 190 Å, a pore volume of around 2.1 cc/g and a chromium content of around 1 wt%

based on the weight of the chromium-containing catalyst. The support comprises a silica and titania support.

[0052] The chromium-based catalyst may have been subjected to a reduction and reoxidation process in which at least a portion of the chromium is reduced to a low valance state and then at least a portion of the chromium is reoxidised to a higher valance state. Such a reduction and reoxidation process as known in the art. Preferably, the chromium-based catalyst is reduced in an atmosphere of dry carbon monoxide in known manner at a temperature of from 700 to 900°C, preferably at a temperature of around 860°C. The chromium-based catalyst is then reoxidised in air in known manner at a temperature of from 700 to 900°C, preferably at a temperature of around 760°C. Alternatively, the chromium-based catalyst may have been activated at a relatively low temperature, fluoridised before or after the activation step to increase the activity of the catalyst and then reduced. In this alternative, the chromium-based catalyst may either be a fluorine-containing catalyst which is commercially available, or may be a similar yet non-fluorine-containing catalyst, which is then subjected to a fluoridisation or fluorination step which is performed in known manner. For example, the chromium-based catalyst may be premixed with a fluorine-containing compound such as ammonium boron tetrafluoride (NH<sub>4</sub>BF<sub>4</sub>) in solid form and then heated at elevated temperature so as to react together the catalyst and the fluorine-containing compound. Such a fluorinisation step may be performed before or during the activation step.

[0053] The catalyst is activated in air at a relatively low activation temperature ranging from 450 to 750°C. More preferably, the activation is carried out at a temperature of from 500 to 650°C. A most preferred activation temperature is around 540°C.

[0054] Following the activation step, the second chromium-based catalyst may be subjected to a chemical reduction step employing dry carbon monoxide. The reduction step is preferably carried out at a temperature of from 300 to 500°C. A most preferred reduction temperature is around 370°C.

[0055] In the preferred process of the present invention to form the low molecular weight fraction of relatively high density using a chromium-based catalyst, the polymerisation or copolymerisation process is carried out in the liquid phase comprising ethylene, and where required an alpha-olefinic comonomer comprising from 3 to 10 carbon atoms, in an inert diluent. The comonomer may be selected from 1-butene, 1-pentene, 1-hexene, 4-methyl 1-pentene, 1-heptene and 1-octene. The inert diluent is preferably isobutane. The polymerisation or copolymerisation process is typically carried out at a temperature of from 85 to 110°C, more preferably from 90 to 100°C, and at a pressure of from 20 to 42 bar, more preferably at a minimum pressure of 24 bar.

[0056] Typically, in the polymerisation process the ethylene monomer comprises from 0.5 to 8% by weight, typically around 6% by weight, of the total weight of the

ethylene in the inert diluent. Typically, in the copolymerisation process the ethylene monomer comprises from 0.5 to 8% by weight and the comonomer comprises from 0 to 4% by weight, each based on the total weight of the ethylene monomer and comonomer in the inert diluent.

[0057] The chromium-based catalyst is introduced into the polymerisation reactor. The alkylene monomer, and comonomer if present, are fed into the polymerisation reactor and the polymerisation product of HDPE is discharged from the reactor and separated from the diluent which can then be recycled.

#### ZIEGLER-NATTA CATALYSTS

[0058] In the preferred process of the present invention, the homopolymerisation process with optional copolymerisation, using a Ziegler-Natta catalyst to produce a polyethylene having a monomodal molecular weight distribution, is carried out in the liquid phase in an inert diluent, the reactants comprising ethylene and hydrogen for homopolymerisation and for copolymerisation ethylene and an alpha-olefinic comonomer comprising from 3 to 8 carbon atoms. The comonomer may be selected from 1-butene, 1-pentene, 1-hexene, 4-methyl 1-pentene, 1-heptene and 1-octene. The inert diluent may comprise isobutane.

[0059] The polymerisation process is preferably carried out at a temperature of from 50 to 120°C, more preferably from 60 to 110°C, under an absolute pressure of 1 to 100 bar.

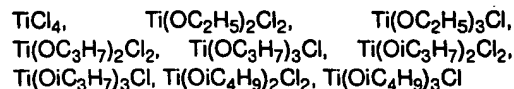
[0060] In the reactor, the ethylene monomer preferably comprises from 0.1 to 3% by weight based on the total weight of the ethylene monomer in the inert diluent and the hydrogen comprises from 0.1 to 2 mol% on the same basis. A particularly preferred composition in the reactor comprises 1% by weight ethylene and 0.8 mol% hydrogen. If a minor degree of copolymerisation is also carried out in the reactor, an alpha-olefinic comonomer as described above, typically hexene, is also introduced into the reactor. The proportion of comonomer introduced is limited to an amount whereby the density of the polyethylene produced in the reactor is at least 0.96g/ml. The polymerisation product from the reactor preferably has a melt index MI2 of from 5 to 200g/10min, more preferably from 25 to 100g/10min, the melt index MI2 being measured determined using the procedures of ASTM D1238 using a load of 2.16kg at a temperature of 190°C. The melt index MI2 is broadly inversely indicative of the molecular weight of the polymer. In other words, a low melt index is indicative of a high molecular weight for the polymer and vice versa. Typically, the polyethylene produced in the reactor has a density of over 0.96g/ml, more typically around 0.97g/ml.

[0061] The Ziegler-Natta catalyst preferably consists of a transition metal component (compound A) which is the reaction product of an organomagnesium com-

pound with a titanium compound and an organoaluminum component (compound B).

[0062] As transition metal compounds suitable for the preparation of component A, there are used tetravalent halogenated titanium compounds, preferably titanium compounds of the general formula  $TiX_n(OR)_{4-n}$  in which n is 1 to 4, X stands for chlorine or bromine, and R for identical or different hydrocarbon radicals, especially straight-chain or branched alkyl groups having 1 to 18, preferably 1 to 10, carbon atoms.

[0063] Examples thereof are:



[0064] In some cases, it may be advantageous to prepare the halogeno-ortho-titanic acid esters of the above formula in situ by reacting the respective ortho-titanic acid ester with  $TiCl_4$  in a corresponding proportion.

[0065] This reaction is advantageously carried out at temperatures of from 0 to 200°C, the upper temperature limit being determined by the decomposition temperature of the tetravalent halogenated titanium compound used; it is advantageously carried out at temperatures of from 60 to 120°C.

[0066] The reaction may be effected in inert diluents, for example aliphatic or cycloaliphatic hydrocarbons as are currently used for the low pressure process such as butane, pentane, hexane, heptane, cyclohexane, methyl-cyclohexane as well as aromatic hydrocarbons, such as benzene or toluene; hydrogenated Diesel oil fractions which have been carefully freed from oxygen, sulphur compounds and moisture are also useful.

[0067] Subsequently, the reaction product of magnesium alcoholate and tetravalent halogenated titanium compound which is insoluble in hydrocarbons is freed from unreacted titanium compound by washing it several times with one of the above inert diluents in which the titanium-(IV)-compound used is readily soluble.

[0068] For preparing component A, magnesium alcoholates, preferably those of the general formula  $Mg(OR)_2$  are used, in which R stands for identical or different hydrocarbon radicals, preferably straight-chain or branched alkyl groups having 1 to 10 carbon atoms; magnesium alcoholates having alkyl groups from 1 to 4 carbon atoms are preferred. Examples thereof are  $Mg(OCH_3)_2$ ,  $Mg(OC_2H_5)_2$ ,  $Mg(OC_3H_7)_2$ ,  $Mg(OiC_3H_7)_2$ ,  $Mg(OC_4H_9)_2$ ,  $Mg(OiC_4H_9)_2$ ,  $Mg(OCH_2-CH_2-C_6H_5)_2$ .

[0069] The magnesium alcoholates can be prepared by known methods, for example by reacting magnesium with alcohols, especially monohydric aliphatic alcohols.

[0070] Magnesium alcoholates of the general formula  $X-Mg-OR$  in which X stands for halogen,  $(SO_4)_{1/2}$  carboxylate, especially acetate of OH, and R has the above remaining, may also be used.

[0071] These compounds are, for example, obtained by reacting alcoholic solutions of the corresponding

anhydrous acids with magnesium.

[0072] The titanium contents of component A may be within the range of from 0.05 to 10mg.-atom, per gram of component A. It can be controlled by the reaction time, the reaction temperature and the concentration of the tetravalent halogenated titanium compound used.

[0073] The concentration of the titanium component fixed on the magnesium compound is advantageously in the range of from 0.005 to 1.5mmol, preferably from 0.03 to 0.8mmol, per litre of dispersing agent or reactor volume. Generally, even higher concentrations are possible.

[0074] The organo-aluminium compounds used may be reaction products of aluminium-trialkyl or aluminium-dialkyl hydrides with hydrocarbon radicals having 1 to 16 carbon atoms, preferably  $\text{Al}(\text{iBu})_3$  or  $\text{Al}(\text{iBu})_2\text{H}$  and diolefins containing 4 to 20 carbon atoms, preferably isoprene; for example aluminium isoprenyl.

[0075] Furthermore, suitable as component B are chlorinated organo-aluminium compounds, for example dialkyl-aluminium monochlorides of the formula  $\text{R}_2\text{AlCl}$  or alkyl-aluminium sesquichlorides of the formula  $\text{R}_3\text{Al}_2\text{Cl}_3$ , in which formulae R stands for identical or different hydrocarbon radicals, preferably alkyl groups having 1 to 16 carbon atoms, preferably 2 to 12 carbon atoms, for example  $(\text{C}_2\text{H}_5)_2\text{AlCl}$ ,  $(\text{iC}_4\text{H}_9)_2\text{AlCl}$ , or  $(\text{C}_2\text{H}_5)_3\text{Al}_2\text{Cl}_3$ .

[0076] It is advantageous to use, as component B, aluminium-trialkyls of the formula  $\text{AlR}_3$  or aluminium-dialkyl hydrides of the formula  $\text{AlR}_2\text{H}$ , in which formulae R stands for identical or different hydrocarbons, preferably alkyl groups having 1 to 16, preferably 2 to 6, carbon atoms, for example  $\text{Al}(\text{C}_2\text{H}_5)_3$ ,  $\text{Al}(\text{C}_2\text{H}_5)_2\text{H}$ ,  $\text{Al}(\text{C}_3\text{H}_7)_3$ ,  $\text{Al}(\text{C}_3\text{H}_7)_2\text{H}$ ,  $\text{Al}(\text{iC}_4\text{H}_9)_3$ , or  $\text{Al}(\text{iC}_4\text{H}_9)_2\text{H}$ .

[0077] The organoaluminium may be used in a concentration of from 0.5 to 10mmol per litre of reactor volume.

[0078] Optionally, a cocatalyst such as a triethylaluminium (TEAL) is employed in the reactor, for example in an amount of around 250ppm by weight based on the weight of the inert diluent.

#### METALLOCENE CATALYSTS

[0079] The second or third polyethylene may be produced using a metallocene catalyst other than component A or B which is then physically blended with the first polyethylene. The metallocene catalyst preferably has the following general formula:

$\text{Cp}_2\text{MX}_n$ , where Cp is a substituted or unsubstituted cyclopenta dienyl group; M is a transition metal from Group IVB of the Periodic Table or vanadium; X is a halogen or a hydrocarbyl group having from 1-10 carbon atoms; and n is the valancy of the metal M minus 2. A typical metallocene catalyst is (n-butyl Cp) $_2\text{ZrCl}_2$  on a silica support with methyl aluminum oxane as a cocatalyst.

[0080] According to the present invention, each polyethylene is produced individually in a reactor, preferably a loop reactor, and then chemically blended together by using a plurality of reactors in series and/or physically blended together for example by extrusion or melt blending. In this way, the low molecular weight and high molecular weight parts of the polyethylene pipe resin can be produced in separate reactors.

[0081] The invention will now be described in further detail, by way of example only, with reference to the following non-limiting Examples.

#### Example 1

##### Catalyst Preparation

[0082]  $(\text{Ph}_2\text{C})(\text{Me}_3\text{SiCp})\text{FluZrCl}_2$  was prepared in accordance with the method of Razavi and Ferrara as published in Journal of Organometallic Chemistry, 435(1992) pages 299 to 310.

[0083] The support used was a silica having a total pore volume of 4.22 ml/g and a surface area of 322  $\text{m}^2/\text{g}$ . This silica is further prepared by drying in high vacuum on a schlenk line for three hours to remove the physically absorbed water. 5 g of this silica are suspended in 50 ml of toluene and placed in a round bottom flask equipped with magnetic stirrer, nitrogen inlet and dropping funnel.

[0084] An amount of 0.31 g of the metallocene is reacted with 25 ml of methylalumoxane (MAO 30 wt% in toluene) at a temperature of 25°C during 10 minutes to give a solution mixture of the corresponding metallocene cation and the anionic methylalumoxane oligomer.

[0085] Then the resulting solution comprising the metallocenium cation and the anionic methylalumoxane oligomer is added to the support under a nitrogen atmosphere via the dropping funnel which is replaced immediately after with a reflux condenser. The mixture is heated to 110°C for 90 minutes. Then the reaction mixture is cooled down to room temperature, filtered under nitrogen and washed with toluene.

[0086] The catalyst obtained is then washed with pentane and dried under a mild vacuum.

[0087] The catalyst was employed in a copolymerisation process to produce a polyethylene copolymer. In a reactor, the ethylene comprised 8 wt% and the hexene comprised 9.76 wt% based on the weight of the diluent which comprised isobutane. The polymerisation temperature was 70°C. No hydrogen was added to the reactor. The resultant polyethylene copolymer which was obtained was measured to have a density of 0.905 g/ml and an HLMI of 0.034 g/10min. The molecular weight distribution was determined to have the following values: Mn 122.2 kDa; Mw 414 kDa and MWD 3.4.

[0088] This first polyethylene product, was used to constitute a high molecular weight, low density fraction of a polyethylene pipe resin which comprised a physical



blend of three separate polyethylenes. The second polyethylene comprised a medium density polyethylene homopolymer having a density of 0.951 g/ml and an HLMI of 10 g/10min. The second polyethylene had an Mn of 32.5 kDa; Mw of 145 kDa and MWD of 4.5. The medium density homopolymer was produced using a metallocene catalyst which comprised (nBuCp)<sub>2</sub>ZrCl<sub>2</sub> on a silica carrier (pore volume 1.7 ml/g; surface area 320 m<sup>2</sup>/g) with methyl alumoxane as a co-catalyst in an amount of 50% of the weight of the carrier. The medium density polyethylene was produced using this catalyst at a polymerisation temperature of 80°C with 6 wt% ethylene in the reactor, based on the weight of the diluent with hydrogen gas being added in an amount of 0.5 NI during the reaction.

[0089] The third polyethylene comprised a high density polyethylene copolymer which a density of 0.967 g/ml and an MI<sub>2</sub> of 56g/10min, the MI<sub>2</sub> being measured using the procedures of ASTM D 1238 at a load of 2.16kg at a temperature of 190°C. The third polyethylene had an Mn of 15 kDa; Mw of 72 kDa and MWD of 4.8. The high density fraction was produced using a metallocene catalyst which comprised ethylene bis (4,5,6,7-tetrahydro-1-indenyl) zirconium dichloride which was prepared in accordance with the method of Brintzinger as published in the Journal of Organometallic Chemistry 288 (1995) pages 63 to 67. In the polymerisation process, the polymerisation temperature was 100°C and the hexene comprised 0.02% in the reactor, based on the weight of the diluent and hydrogen gas was supplied at an initial amount of 5 NI/h. In the off gas, there was 7.5 wt% C<sub>2</sub> and 0.007 wt% H<sub>2</sub>.

[0090] The three fractions so formed were physically blended to form a polyethylene resin in the following proportions by weight: 22 wt% of the low density fraction; 38 wt% of the medium density fraction and 40 wt% of the high density fraction. The resultant polyethylene resin had a density of 0.947 g/ml and an HLMI of 18.3 g/10min. The resin had an Mn of 22.4 kDa; Mw of 177 kDa and MWD of 7.9. The multimodal molecular weight distribution is shown in Figure 1. The mechanical properties of the resin were tested. The resin had an energy at break of 77 kJ/m<sup>2</sup>. The energy at break (J<sub>a,c</sub>) was determined using the procedures disclosed in "J-integral studies of crack initiation of a tough high density polyethylene" MKV Chan and JG Williams, International Journal of Fracture 1983, pages 145-159.

#### Example 2

[0091] The catalyst (Ph<sub>2</sub>C)(Me<sub>3</sub>SiCp)FluZrCl<sub>2</sub> of Example 1 was employed in a copolymerisation process to produce a polyethylene copolymer. In a reactor, the ethylene comprised 6 wt% and the hexene comprised 9.7 wt% based on the weight of the diluent which comprised isobutane. The polymerisation temperature was 70°C. No hydrogen was added to the reactor. The resultant polyethylene copolymer which was obtained

was measured to have a density of 0.896 g/ml and an HLMI of 0.12 g/10min.

[0092] This first polyethylene product, was used to constitute a high molecular weight, low density fraction of a polyethylene pipe resin which comprised a physical blend of three separate polyethylenes. The second polyethylene comprised a medium density polyethylene homopolymer having a density of 0.953 g/ml and an HLMI of 2 g/10min. The medium density homopolymer was produced using a chromium-based catalyst which comprised 1 wt% chromium (in the form of oxide) on a silica-alumina support (pore volume 1.1 ml/g; surface area 300m<sup>2</sup>/g). The medium density polyethylene was produced using this catalyst at a polymerisation temperature of 107°C with 5.8 wt% ethylene and 0.08 wt% hexene copolymer in the off-gas of the reactor, with no hydrogen gas being added.

[0093] The third polyethylene comprised a high density polyethylene copolymer which a density of 0.967 g/ml and an MI<sub>2</sub> of 56g/10min. The high density fraction was produced using a metallocene catalyst which comprised ethylene bis (4,5,6,7-tetrahydro-1-indenyl) zirconium dichloride, with the co-catalyst of ethyl aluminoxane, of Example 1. In the polymerisation process, the polymerisation temperature was 100°C and the hexene comprised 0.02% in the reactor, based on the weight of the diluent and hydrogen gas was supplied at an initial amount of 5 NI/h. In the off gas, there was 7.5 wt% C<sub>2</sub> and 0.007 wt% H<sub>2</sub>.

[0094] The three fractions so formed were physically blended to form a polyethylene resin in the following proportions by weight: 21 wt% of the low density fraction; 21 wt% of the medium density fraction and 58 wt% of the high density fraction. The resultant polyethylene resin had a density of 0.949 g/ml and an HLMI of 37.8 g/10min. The mechanical properties of the resin were tested. The resin had an energy at break of 62 kJ/m<sup>2</sup>.

#### Example 3

[0095] The (Ph<sub>2</sub>C)(Me<sub>3</sub>SiCp)FluZrCl<sub>2</sub> catalyst of Example 1 was employed in a copolymerisation process to produce a polyethylene copolymer. In a reactor, the ethylene comprised 8 wt% and the hexene comprised 9.76 wt% based on the weight of the diluent which comprised isobutane. The polymerisation temperature was 70°C. No hydrogen was added to the reactor. The resultant polyethylene copolymer which was obtained was measured to have a density of 0.905 g/ml and an HLMI of 0.03 g/10min. The molecular weight distribution was determined to have the following values: Mn 105 kDa; Mw 461 kDa; and MWD 4.4.

[0096] This first polyethylene product, was used to constitute a high molecular weight, low density fraction of a polyethylene pipe resin which comprised a physical blend of three separate polyethylenes. The second and third polyethylenes comprised a bimodal resin produced using two reactors in series with a Ziegler-Natta cata-

lyst. The second polyethylene comprised a medium density polyethylene homopolymer having a density of 0.948 g/ml and an HLMI of 0.12 g/10min. The second polyethylene had an Mn of 98.5 kDa; Mw of 569 kDa and MWD of 5.8. The medium density homopolymer was produced using a Ziegler-Natta catalyst. The Ziegler-Natta catalyst comprised typically 7.2 wt% Ti, 12.5 wt% Mg and 49 wt% Cl. The medium density polyethylene was produced using this catalyst at a polymerisation temperature of 95°C with 3 wt% ethylene in the reactor, based on the weight of the diluent with no hydrogen gas or comonomer being added.

[0097] The third polyethylene comprised a high density polyethylene homopolymer with a density of 0.9685 g/ml and an MI<sub>2</sub> of 65g/10min. The third polyethylene had an Mn of 9.5 kDa; Mw of 46 kDa and MWD of 4.8. The high density fraction was produced using the same Ziegler-Natta catalyst as for the medium density fraction. In the polymerisation process, the polymerisation temperature was 95°C and the ratio of H<sub>2</sub>/C<sub>2</sub> in the reactor, as the result of supply of hydrogen gas to the reactor, was 0.45. In the off gas, there was 2 wt% C<sub>2</sub>.

[0098] The three fractions so formed were physically blended to form a polyethylene resin in the following proportions by weight: 27 wt% of the low density fraction; 25 wt% of the medium density fraction and 48 wt% of the high density fraction. The resultant polyethylene resin had a density of 0.944 g/ml and an HLMI of 3.9 g/10min. The resin had an Mn of 18.2 kDa; Mw of 339 kDa and MWD of 18.7. The mechanical properties of the resin were tested. The resin had an energy at break of 105 kJ/m<sup>2</sup>.

#### Example 4

[0099] This Example used the metallocene ethylene bis (4,5,6,7-tetrahydro-1-indenyl) zirconium dichloride of Example 1 in two reactors in series to produce a bimodal polyethylene pipe resin.

[0100] The catalyst was employed in a copolymerisation process to produce a polyethylene copolymer. In a first reactor of two serially connected reactors, the ethylene comprised 5 wt% and the hexene comprised 0.01 wt%, each in the off gas, giving a C<sub>6</sub>/C<sub>2</sub> ratio of 0.003. The polymerisation temperature was 90°C. Hydrogen was added to the reactor in an amount of 20NI/h. The resultant polyethylene copolymer which was obtained was measured to have a density of greater than 0.970 g/ml and an HLMI of greater than 20,000 g/10min.

[0101] This first polyethylene product, was used to constitute a low molecular weight, high density fraction of a polyethylene pipe resin which comprised a chemical blend of two separate polyethylenes. The second polyethylene produced in the second of the serially connected reactors using the same catalyst as for the first reactor comprised a low density high molecular weight polyethylene copolymer fraction having a density of 0.923 g/ml and an HLMI of 0.42 g/10min.

[0102] In the polymerisation process to produce the second polyethylene, the polymerisation temperature was 70°C and in the off gas, there was 5.5 wt% C<sub>2</sub> and 1.6 wt% C<sub>6</sub> giving a C<sub>6</sub>/C<sub>2</sub> ratio of 0.29.

[0103] The two fractions so formed were chemically blended in the second reactor to form a polyethylene resin in the following proportions by weight: 50 wt% of the low density fraction; 50 wt% of the high density fraction. The resultant polyethylene resin chemical blend (in its extruded form) had a density of 0.956 g/ml, an MI<sub>5</sub> of 0.27 g/10min and an SR<sub>5</sub> of 25.6 (this being the ratio HLMI/MI<sub>5</sub>). The bimodal molecular weight distribution is shown in Figure 2. The mechanical properties of the resin were tested. The resin survived a notch pipe test (with a notch of 0.63 mm at a pressure of 4.6 mPa at 80°C) for a period of greater than 6000 hours. This indicates good resistance to slow crack growth.

[0104] In comparison, a known polyethylene pipe resin of grade PE 100 made using a Ziegler-Natta catalyst and having a bimodal molecular weight distribution had an MI<sub>5</sub> of 0.27 g/10 min, an SR<sub>5</sub> of 30 and a density of 0.960 g/ml. When subjected to the same notch test, this pipe resin only survived for greater than 1000 hours.

#### Example 5

[0105] The catalyst (Ph<sub>2</sub>C)(Me<sub>3</sub>SiCp)FluZrCl<sub>2</sub> of Example 1 was employed in a copolymerisation process to produce a polyethylene copolymer. In a reactor, the ethylene comprised 6 wt% and the hexene comprised 2.44 wt% based on the weight of the diluent which comprised isobutane. The polymerisation temperature was 80°C. No hydrogen was added to the reactor. The resultant polyethylene copolymer which was obtained was measured to have a density of 0.925 g/ml and an HLMI of 0.08 g/10min, the polyethylene had an Mn of 124 kDa, an Mw of 424 kDa and a dispersion index D of 3.4.

[0106] This first polyethylene product was used to constitute a first fraction of an LLDPE bimodal polyethylene resin which comprised a physical blend of two separate polyethylenes. The second polyethylene comprised an LLDPE polyethylene copolymer also having a density of 0.925 g/ml and having an MI<sub>2</sub> of 60 g/10min. The second LLDPE copolymer was produced using the metallocene catalyst of Example 4. The metallocene catalyst comprised 4 wt% on the support. The LLDPE polyethylene was produced using this catalyst at a polymerisation temperature of 90°C with 3.6 wt% ethylene and 1.79 wt% hexene comonomer in the off-gas of the reactor, with 8.5 NI/h of hydrogen gas being added. The second polyethylene had an Mn of 16.7 kDa, an Mw of 53 kDa and a dispersion index D of 3.1.

[0107] The two fractions so formed were physically blended to form a bimodal polyethylene resin in the following proportions by weight: 50 wt% of the first fraction and 50 wt% of the second fraction. The resultant polyethylene resin had a density of 0.925 g/ml and an HLMI

of 7.2 g/10min. The LLDPE resin blend had an Mn of 30.3 kDa, an Mw of 241 kDa and a dispersion index D of 8.0. The gas phase chromatograph of the physical blend is shown in Figure 3.

#### Example 6

[0108] The catalyst  $(\text{Ph}_2\text{C})(\text{Me}_3\text{SiCp})\text{FluZrCl}_2$  of Example 5 was employed in a copolymerisation process to produce a polyethylene copolymer. In a reactor, the ethylene comprised 8 wt% and the hexene comprised 9.76 wt% based on the weight of the diluent which comprised isobutane. The polymerisation temperature was 70°C.

[0109] No hydrogen was added to the reactor. The resultant polyethylene copolymer which was obtained was measured to have a density of 0.905 g/ml and an HLMI of less than 0.1 g/10min, the polyethylene had an Mn of 100 kDa, an Mw of 394 kDa and a dispersion index D of 3.9.

[0110] This first polyethylene product was used to constitute a first fraction of an LLDPE bimodal polyethylene resin which comprised a physical blend of two separate polyethylenes. The second polyethylene comprised an LLDPE polyethylene copolymer having a density of 0.930 g/ml and having an  $\text{MI}_2$  of 45 g/10min. The second LLDPE copolymer was produced using the metallocene catalyst of Example 4. The metallocene catalyst comprised 4 wt% on the support. The LLDPE polyethylene was produced using this catalyst at a polymerisation temperature of 90°C with 3.6 wt% ethylene and 1.52 wt% hexene comonomer in the off-gas of the reactor, with 7.0 NI/h of hydrogen gas being added. The second polyethylene had an Mn of 19 kDa, an Mw of 74 kDa and a dispersion index D of 3.9.

[0111] The two fractions so formed were physically blended to form a bimodal polyethylene resin in the following proportions by weight: 50 wt% of the first fraction and 50 wt% of the second fraction. The resultant polyethylene resin had a density of 0.918 g/ml and an HLMI of 7.4 g/10min. The LLDPE resin blend had an Mn of 32.0 kDa, an Mw of 235 kDa and a dispersion index D of 7.3. The gas phase chromatograph of the physical blend is shown in Figure 4.

#### Example 7

[0112] This Example used the metallocene ethylene big (4,5,6,7-tetrahydro-1-indenyl) zirconium dichloride of Example 1 in two reactors in series to produce a bimodal LLDPE polyethylene resin. The catalyst comprised 4 wt% on the support.

[0113] The catalyst was employed in a copolymerisation process to produce a polyethylene copolymer. In a first reactor of two serially connected reactors, the ethylene comprised 4 wt% and the hexene comprised 3.6 wt%, each in the off gas. The polymerisation temperature was 70°C and the residence time was 70 minutes.

Hydrogen was added to the reactor in an amount of 0.2 NI/h.

[0114] This first polyethylene product was used to constitute a first LLDPE fraction of an LLDPE bimodal resin which comprised a chemical blend of two separate polyethylenes. The second polyethylene produced in the second of the serially connected reactors using the same catalyst as for the first reactor comprised an LLDPE polyethylene.

[0115] In the polymerisation process to produce the second polyethylene, the polymerisation temperature was 90°C for a residence time of 180 minutes, and in the off gas, there was 6 wt% ethylene and 0 wt% hexene. Hydrogen was added to the reactor in an amount of 3.0 NI/h.

[0116] The two fractions so formed were chemically blended in the second reactor to form a polyethylene resin in the following proportions by weight: 50 wt% of the first fraction; 50 wt% of the second fraction. The resultant polyethylene resin chemical blend (in its extruded form) had a density of 0.925 g/ml, an  $\text{MI}_2$  of 0.2 g/10min, an HLMI of 17.6 g/10min and an  $\text{SR}_2$  of 88 (this being the ratio  $\text{HLMI}/\text{MI}_2$ ). The bimodal molecular weight distribution is shown in Figure 5. The resin had an Mn of 24.4 kDa, an Mw of 187 kDa and a dispersion index D of 7.7.

#### Comparative Example 1

[0117] The catalyst  $(\text{Ph}_2\text{C})(\text{Me}_3\text{SiCp})\text{FluZrCl}_2$  of Example 1 was employed in a copolymerisation process to produce a polyethylene copolymer. In a reactor, the ethylene comprised 6 wt% and the hexene comprised 9.76 wt% based on the weight of the diluent which comprised isobutane. The polymerisation temperature was 70°C.

[0118] No hydrogen was added to the reactor. The resultant polyethylene copolymer which was obtained was measured to have a density of 0.898 g/ml and an HLMI of 0.05 g/10min.

[0119] This first polyethylene product, was used to constitute a high molecular weight, low density fraction of a polyethylene pipe resin which comprised a physical blend of three separate polyethylenes. The second polyethylene comprised a medium density polyethylene homopolymer having a density of 0.956 g/ml an  $\text{MI}_2$  of 0.85 g/10min and an HLMI of 20 g/10min. The medium density homopolymer was produced using the same metallocene catalyst  $(\text{nBuCp})_2\text{ZrCl}_2$  of Example 1 on a silica support (pore volume 1.8 ml/g; surface area 750  $\text{m}^2/\text{g}$ ) with methyl alumoxane as co-catalyst. The medium density polyethylene was produced using this catalyst at a polymerisation temperature of 80°C with 6 wt% ethylene, no hexene copolymer and 2 NI hydrogen gas being added.

[0120] The third polyethylene comprised a high density polyethylene copolymer with a density of 0.967 g/ml and an  $\text{MI}_2$  of 56g/10min. The high density fraction was

produced using a metallocene catalyst which comprised ethylene bis (4,5,6,7-tetrahydro-1-indenyl) zirconium dichloride, with the co-catalyst of ethyl aluminoxane, of Example 1. In the polymerisation process, the polymerisation temperature was 100°C and the hexene comprised 0.02% in the reactor, based on the weight of the diluent and hydrogen gas was supplied at an initial amount of 5 Nl/h. In the off gas, there was 7.5 wt% C<sub>2</sub>.

[0121] The three fractions so formed were physically blended to form a polyethylene resin in the following proportions by weight: 14.6 wt% of the low density fraction; 73.4 wt% of the medium density fraction and 12 wt% of the high density fraction. The resultant polyethylene resin had a density of 0.9466 g/ml and an HLMI of 8.2 g/10min. The mechanical properties of the resin were tested. The resin had an energy at break only 44 kJ/m<sup>2</sup>. This shows that using a proportion of the linear low density polyethylene of at least 15 wt% in the pipe resin is required to improve the rapid crack propagation resistance.

#### Comparative Example 2

[0122] A bimodal resin was produced using two reactors in series with a Ziegler-Natta catalyst. The first polyethylene fraction comprised a low density polyethylene copolymer having a density of 0.9252 g/ml and an HLMI of 0.263 g/10min. The Ziegler-Natta catalyst comprised 6.9 wt% Ti, 13.2 wt% Mg and 49.8 wt% Cl. The low density polyethylene fraction was produced using this catalyst at a polymerisation temperature of 80°C with 1 wt% ethylene and 4.5 wt% hexene in the first reactor, based on the weight of the diluent. Hydrogen gas was added in an amount of 0.01 vol%.

[0123] The second polyethylene fraction comprised a high density polyethylene homopolymer with a density of 0.9685 g/ml and an M<sub>L2</sub> of 65g/10min. The high density fraction was produced using the same Ziegler-Natta catalyst as for the low density fraction in the second reactor. In the polymerisation process, the polymerisation temperature was 95°C with 1.95 wt% ethylene and no hexene. Hydrogen was added in an amount of 0.9 vol%. The two fractions were chemically blended in the second reactor to form a polyethylene resin in the following proportions by weight: 48 wt% of the low density fraction; and 52 wt% of the high density fraction. The resultant polyethylene resin which typifies a known PE100 bimodal pipe resin had a density of 0.949 g/ml and an HLMI of 10.3 g/10min. The resin had an Mn of 15.5 kDa; Mw of 266 kDa and MWD of 17.1. The mechanical properties of the resin were tested. The resin had an energy at break of only 43 kJ/m<sup>2</sup>.

#### Comparative Example 3

[0124] In this Comparative Example two resins produced separately using the Ziegler-Natta catalyst of

Comparative Example 2 were physically blended to produce a pipe resin. The first resin had a density of 0.9208 g/ml, an HLMI of 0.53 g/10min, an Mn of 58.7 kDa, an Mw of 476 kDa and an MWD of 8.1.

[0125] This first polyethylene resin, was used to constitute a high molecular weight, low density fraction of a polyethylene pipe resin which comprised a physical blend of the two separate polyethylenes. The second polyethylene resin comprised a high density polyethylene having a density of 0.9676 g/ml, an M<sub>L2</sub> of 42 g/10min, an Mn of 10.7 kDa, an Mw of 48 kDa and an MWD of 4.5.

[0126] The two fractions were physically blended to form a polyethylene resin in the following proportions by weight: 40 wt% of the low density fraction and 60 wt% of the high density fraction. The resultant polyethylene resin blend (in its extruded form) had a density of 0.9502 g/ml, an HLMI of 24.3 g/10min, an Mn of 16.6 kDa, an Mw of 226 kDa and an MWD of 13.6. The mechanical properties of the resin were tested. The resin had an energy at break of only 19.8 kJ/m<sup>2</sup>.

#### Claims

1. A process for the preparation of polyethylene resins having a multimodal molecular weight distribution which comprises:

(i) contacting ethylene monomer and a comonomer comprising an alpha-olefin having from 3 to 10 carbon atoms with a first catalyst system in a first reactor under first polymerisation conditions to produce a product comprising a first polyethylene having a first molecular weight and a first density and the first catalyst system comprising (a) a metallocene catalyst selected from one of components A or B, component A comprising a bis tetrahydroindenyl compound of the general formula (IndH<sub>4</sub>)<sub>2</sub>R''MQ<sub>2</sub> in which each Ind is the same or different and is indenyl or substituted indenyl, R'' is a bridge which comprises a C<sub>1</sub>-C<sub>20</sub> alkylene radical, a dialkyl germanium or silicon or siloxane, or an alkyl phosphine or amine radical, which bridge is substituted or unsubstituted, M is a Group IVB transition metal or vanadium and each Q is hydrocarbyl having 1 to 20 carbon atoms or halogen and component B comprising a metallocene catalyst of general formula R''(CpR<sub>m</sub>)(Cp'R<sub>n</sub>)MQ<sub>2</sub>, wherein Cp is a cyclopentadienyl moiety, Cp' is a substituted or unsubstituted fluorenyl ring; each R is independently hydrogen or hydrocarbyl having 1 to 20 carbon atoms in which 0 ≤ m ≤ 4; each R' is independently hydrocarbyl having 1 to 20 carbon atoms in which 0 ≤ n ≤ 8; R'', M and Q are each as defined above, the metallocene component B having a centroid-M-centroid angle in

the range 105° to 125°; and (b) a cocatalyst which activates the catalyst component;

(ii) providing a second polyethylene having a second lower molecular weight and higher density than the first molecular weight; and

(iii) mixing together the first and second polyethylenes to form a polyethylene resin having a multimodal molecular weight distribution.

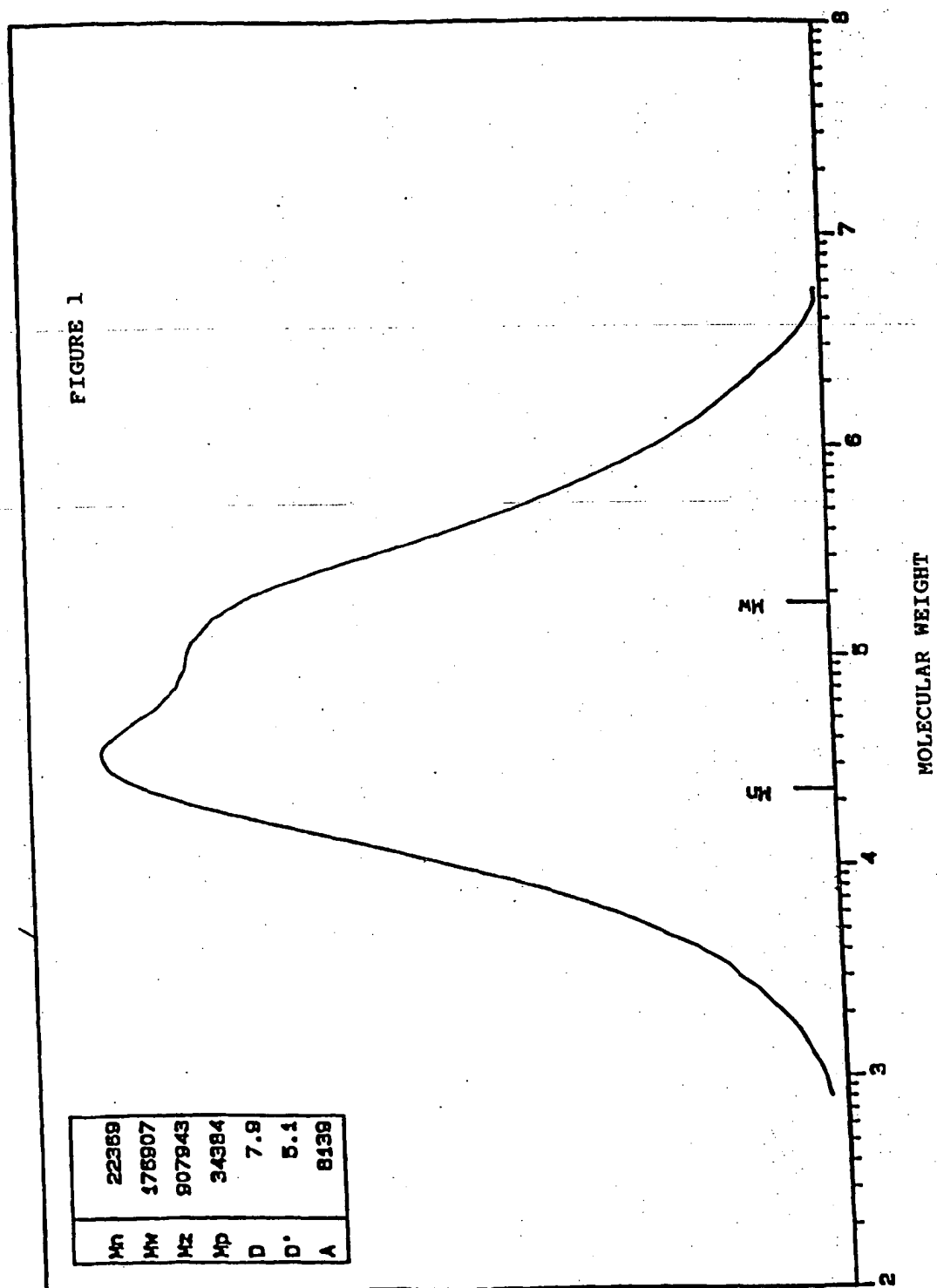
2. A process according to claim 1 wherein the first polyethylene is monomodal.
3. A process according to claim 1 wherein the first polyethylene is bimodal.
4. A process according to any foregoing claim wherein the second polyethylene has a monomodal molecular weight distribution and has been produced using a metallocene catalyst, a Ziegler-Natta catalyst or a chromium-oxide based catalyst.
5. A process according to any one of claims 1 to 3 wherein the second polyethylene has a bimodal molecular weight distribution and has been produced using a metallocene catalyst, a Ziegler-Natta catalyst or a chromium-oxide based catalyst.
6. A process according to any foregoing claim wherein the first and second polyethylenes are mixed together with a third polyethylene to provide a trimodal molecular weight distribution in the resultant polyethylene resin.
7. A process according to claim 6 wherein the third polyethylene is produced using a metallocene catalyst, a Ziegler-Natta catalyst or a chromium-oxide based catalyst.
8. A process according to any foregoing claim wherein the first and second polyethylenes are mixed by physical blending.
9. A process according to any foregoing claim wherein the first and second polyethylenes are mixed by chemical blending.
10. A process according to claim 9 wherein the first and second polyethylenes are made in two serially connected reactors using a common metallocene catalyst component A or B.
11. A process according to claim 10 wherein the resin has a trimodal molecular weight distribution and comprises a third polyethylene which is chemically blended with the first and second polyethylenes and has been produced in a third reactor serially con-

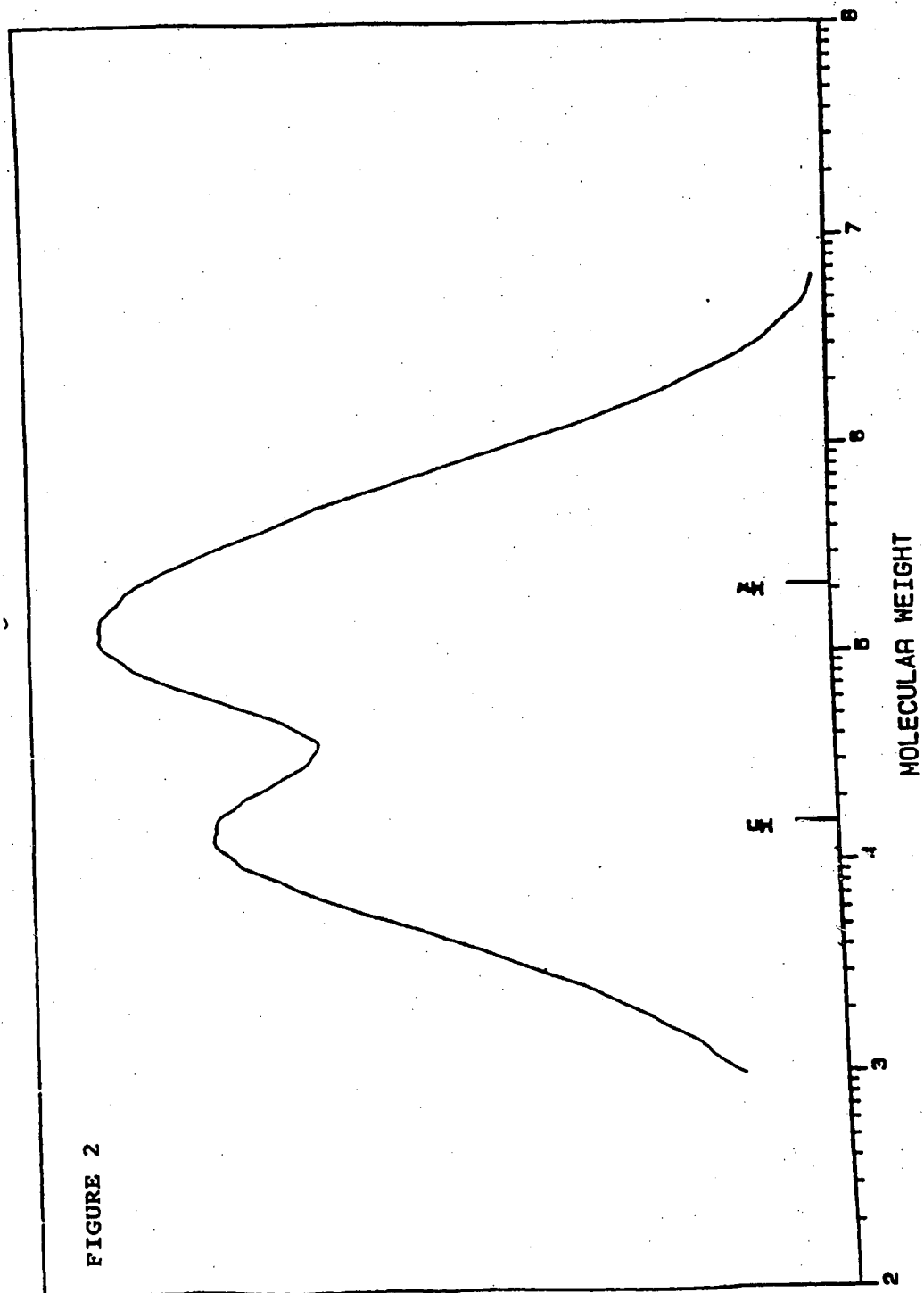
nected to the two serially connected reactors.

12. A process according to claim 10 wherein the first and second polyethylenes are chemically blended, and a third polyethylene is physically blended therewith to produce a trimodal molecular weight distribution.
13. A process according to claim 8 wherein the polyethylene resin has a bimodal molecular weight distribution and is produced by physically blending the first and second polyethylenes together.
14. A process according to claim 8 wherein the polyethylene resin has a trimodal molecular weight distribution and is produced by physically blending together the first and second polyethylenes together with a third polyethylene having a different molecular weight distribution therefrom.
15. A process according to claim 1 wherein the polyethylene pipe resin has a high molecular weight, low density fraction produced by a metallocene catalyst of component B, a medium density fraction produced by a chromium-based catalyst and a high density fraction produced by a metallocene catalyst of component A, these three fractions being physically blended together to form the resultant polyethylene resin, and the low and high density fractions together defining a bimodal distribution.
16. A process according to claim 1 wherein the polyethylene pipe resin comprises a physical blend of three polyethylenes produced by three different metallocene catalysts, the resin including a low density fraction produced using the metallocene catalyst of component B, a medium density fraction produced using a metallocene catalyst different from components A and B and a high density fraction produced using a metallocene catalyst of component A.
17. A process according to claim 1 wherein the polyethylene type resin comprises a low density fraction produced using the metallocene catalyst of component B, a medium density fraction using a first Ziegler-Natta catalyst and a high density fraction produced using a second Ziegler-Natta catalyst, the medium and high density fractions together defining a bimodal distribution.
18. A process according to claim 1 wherein the polyethylene pipe resin is produced using a single metallocene catalyst of component A or B in two reactors in series to produce a bimodal molecular weight distribution.
19. A process according to claim 18 wherein the first reactor of the serially connected reactors a high

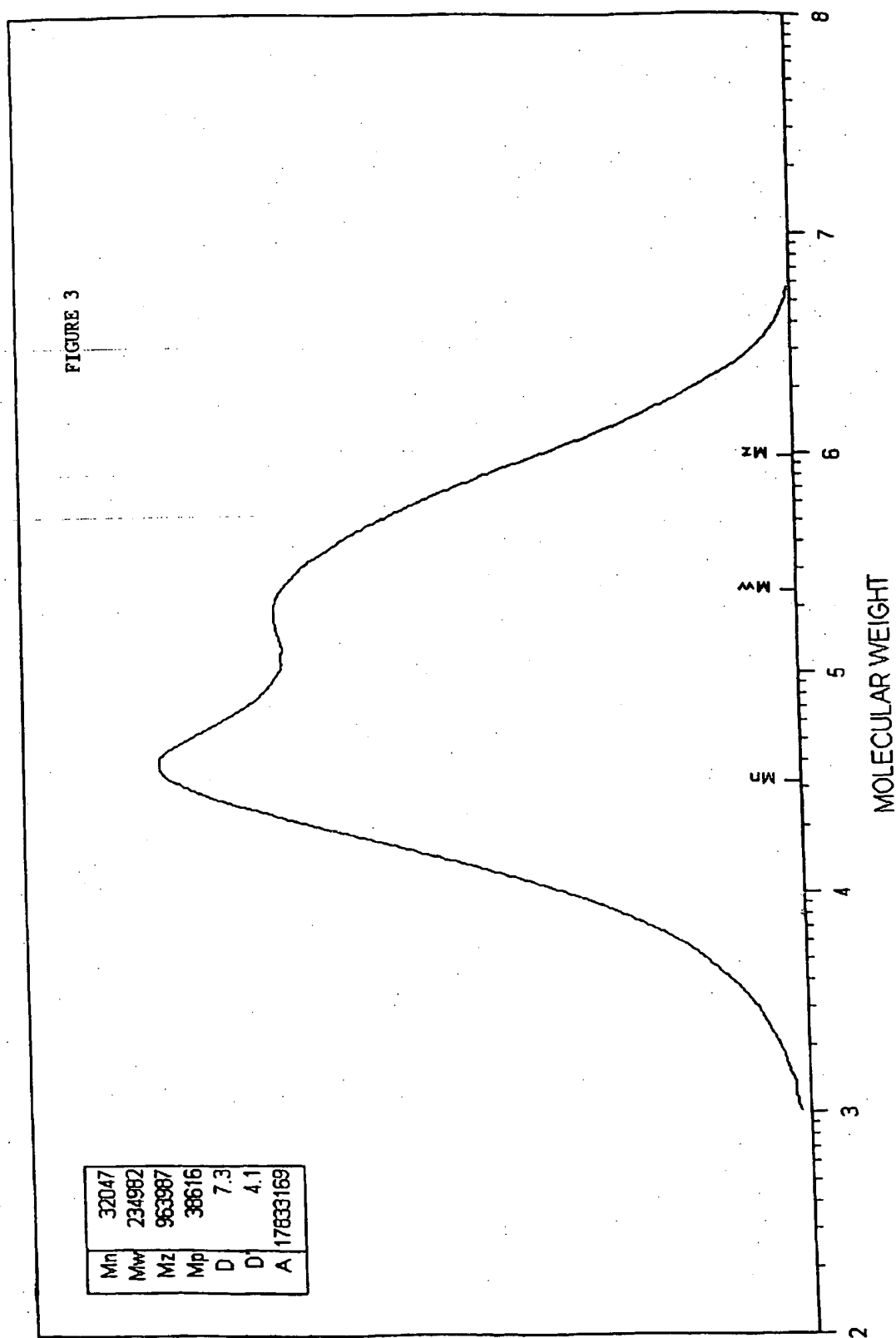
density polyethylene resin is produced which is substantially a homopolymer and in the second reactor the operating conditions are changed and the upper-olefinic copolymer is introduced to produce a low density fraction with high comonomer incorporation. 5

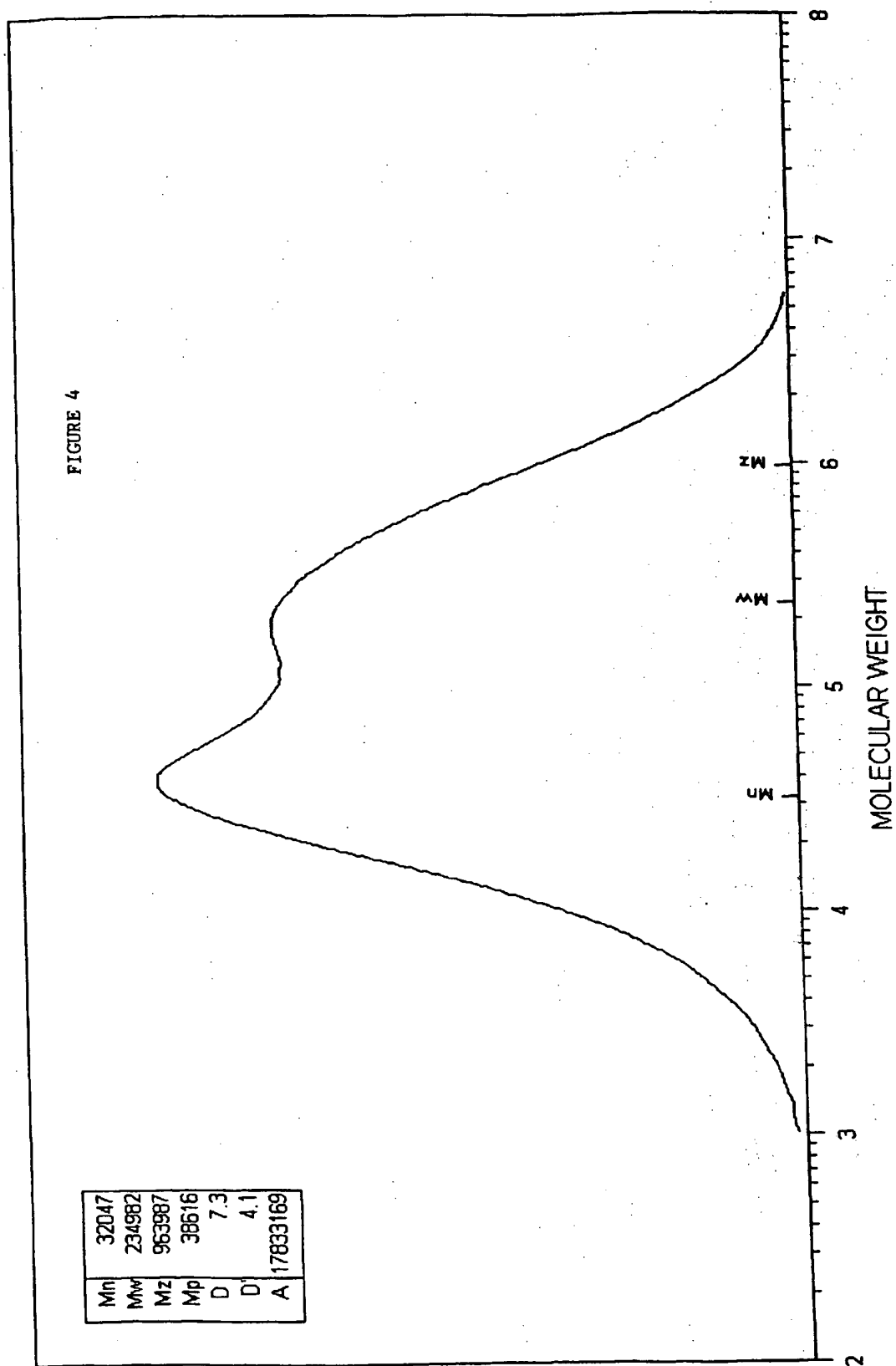
20. A process according to any foregoing claim wherein the polyethylene resin is a pipe resin and the first polyethylene has a density of around 0.9 g/ml and comprises at least 15% by weight of the polyethylene resin. 10
21. A process according to any foregoing claim wherein R" is Ph-C-Ph. 15
22. A process according to claim 1 wherein the first and second polyethylenes are each produced using the metallocene catalyst of component A or B and are linear low density polyethylenes having a density of not more than 0.930 g/ml. 20
23. A process according to claim 22 wherein the first and second polyethylenes are physically blended and the first and second polyethylenes are produced using the metallocene catalysts of component B or of component A respectively. 25
24. A process according to claim 23 wherein each of the first and second polyethylenes has a density of around 0.925 g/ml. 30
25. A process according to claim 25 wherein the first polyethylene has a density of around 0.905 g/ml and the second polyethylene has a density of around 0.930 g/ml. 35
26. A process according to any one of claims 23 to 25 wherein the physical blend comprises substantially equal parts by weight of the first and second polyethylenes and has an HLMI of from 7 to 7.5 g/10min. 40
27. A process according to claim 22 wherein the first and second polyethylenes are chemically blended and are produced using the metallocene catalyst of component A. 45
28. A process according to any one of claims 22 to 26 wherein the first and second polyethylenes together have a bimodal molecular weight distribution. 50

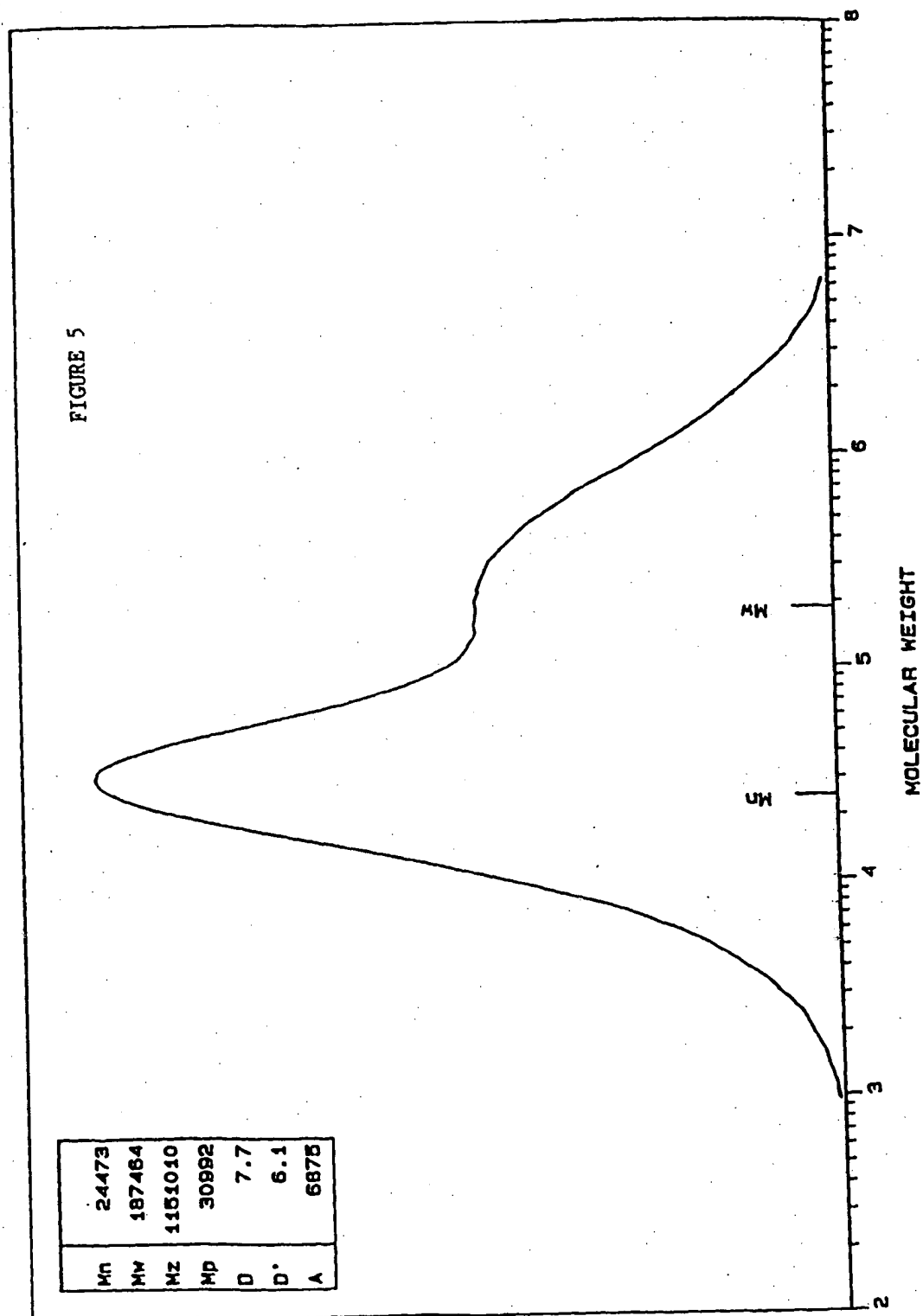














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The present search report has been drawn up for all claims			
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